Combination of Precise Orbit Solutions for Sentinel-3A using Variance Component Estimation

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Introduction

Today the orbits of various Earth observation satellites are routinely calculated from Global Positioning System data on an operational basis. These calculations can differ in many ways, e.g., in terms of used background models, adopted orbit parametrizations, or the used processing software. This raises the question whether it is possible to derive an orbit with superior quality by combining different solutions. In this presentation we use the Low Earth Orbiting (LEO) satellite Sentinel-3A to further address this question. Together with the Sentinel-3B, the two Sentinel-3 satellites form a pair of Earth observation satellites. They belong to the fleet of the Copernicus Earth observation programme, established by the EU and ESA in 2012 to address and answer environmental and safety issues.

The task of Sentinel-3A is ocean observation. It measures land and ocean colours, land and sea temperature and sea surface and ice topography. It was launched on 16 February 2016 from space port Plessezk.

Figure 1: Sentinel-3A (©ESA)

It is equipped with two GPS receivers in order to enable precise orbit determination (POD). Sentinel-3A orbital solutions are routinely computed by the following Analysis Centers (ACs):

- GMV (Grupo Mecánica del Vuelo)
- AIUB (Astronomical Institute, University of Bern)
- TUM (Technische Universität München)
- CNES (Centre National d'Etudes Spatiales)
- TUD (Delft University of Technology)
- EUM (European Organisation for the Exploitation of Meteorological Satellites)
- DLR (Deutsches Zentrum für Luft- und Raumfahrt)
- ESOC (European Space Operations Center of ESA)

These ACs are members of the so-called Sentinel POD QWG (Quality working group). All institutions of this QWG regularly provide independent orbit solutions for the Sentinel-1,-2,-3 satellites, see e.g. [3]. The solutions are produced by different software packages and are based on different reduced-dynamic orbit determination approaches. In order to combine the different solutions we use the method of variance component estimation (VCE) [4]. Due to the reduced-dynamic orbit modeling, the individual solutions are, however, not primarily affected by random errors but rather by systematic errors. In this presentation we make an attempt to assess different types of systematic errors affecting the combined solution by using simulation studies. In order to transfer the results of the simulations to reality, the simulation has to reflect the main characteristics of real orbit errors.
Since the estimation of variance components is an iterative procedure, it is furthermore of interest to investigate the convergence behaviour and the added value of performing more than one iterations.
SLR measurements are eventually used to assess the quality of the combined solution when using real orbit solutions from the ACs of the Sentinel POD QWG. In addition to the combined solution, the individual solutions are also validated by SLR.

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Comparison of individual solutions

The different solutions are first compared against each other. Since one may loose track from a cross-comparison between all solutions, we select a reference solution and compute the differences between this solution and all other solutions. Note that we do not apply a Helmert transformation. The selected reference solution is the official orbit solution from the Copernicus POD Service (CPOD) computed by GMV. The comparison was performed for the period from 1 January 2017 to 27 January 2018.

[cm]	AIUB	TUM	CNES	DLR	TUD	ESOC	EUM
Radial-RMS	1.28	0.97	0.59	1.05	0.95	0.62	0.72
Along-RMS	1.57	1.71	1.52	1.41	1.24	1.32	1.78
Cross-RMS	1.20	1.30	0.80	1.29	1.25	1.69	1.46
3D-RMS	1.35	1.33	0.97	1.25	1.15	1.21	1.32
Radial-MEAN	-0.80	-0.18	0.06	-0.59	-0.60	0.07	-0.10
Along-MEAN	-0.25	-0.58	-0.52	-0.01	-0.06	-0.69	-0.55
Cross-MEAN	-0.69	-0.69	-0.48	-0.80	-0.86	-1.32	0.12
3D-MEAN	-0.58	-0.49	-0.31	-0.47	-0.51	-0.65	-0.18
Radial-STD	0.99	0.95	0.59	0.85	0.73	0.61	0.71
Along-STD	1.53	1.60	1.41	1.41	1.23	1.23	1.70
Cross-STD	0.93	0.98	0.75	0.01	0.89	0.92	1.45
3D-STD	1.15	1.18	0.92	1.08	0.95	0.92	1.29

Table 1: Orbit comparison in the local orbital frame, CPOD vs. other solutions

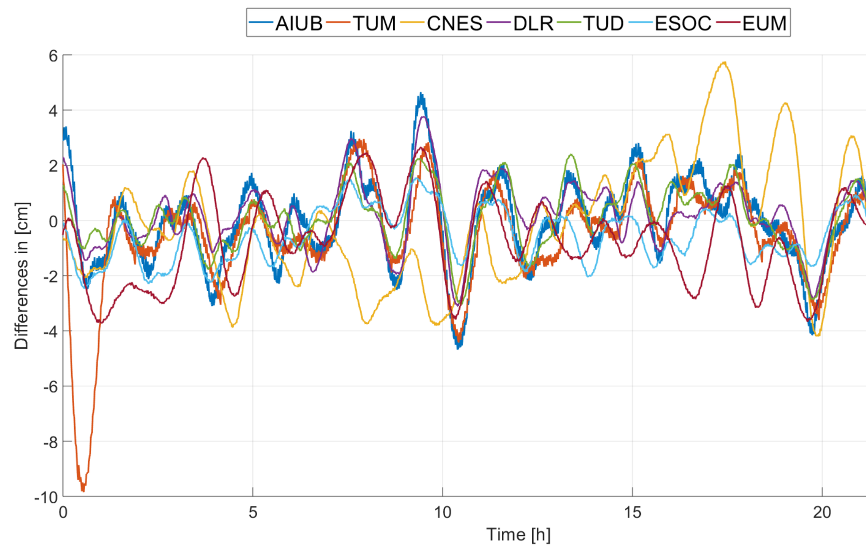

Figure 2: Along-track differences between individual solutions and CPOD solution for 24.09.17

Since the different solutions may also show systematic differences, e.g. systematic radial biases (see Table 1), a Helmert transformation with respect to a fixed reference solution would be advantageous to quantify the remaining differences. By such a transformation it could in particular be possible to remove a systematic offset between two solutions. Figure 2 shows the differences of the individual solutions in along-track direction with respect to the CPOD solution for one example day.

Theory

The combined solution shall be calculated from the individual solutions for each epoch as a weighted average independent of the other epochs. The weights are a priori unknown and shall be determined using VCE. Under these assumptions, the following explicit formulas result [1]. Note that correlations between components and positions referring to different epochs are neglected.

Method of Combination

Iteration 0:

$$\hat{x}_0 = \frac{1}{n}\sum_k x_k \text{ with } x_k = \text{orbit solution of AC}_k$$

$$w_{k,0} = \frac{1}{n}\ \forall k, k = 1, ..., n$$

Iteration $i > 0$:

$$\hat{x}_i = \frac{1}{\sum_k w_{k,i}}\sum_k w_{k,i} x_k$$

$$\text{with } w_{k,i} = \left(1 - \frac{w_{k,i-1}}{\sum_k w_{k,i-1}}\right)\cdot\left(\frac{1}{RMS(d_{k,i-1})}\right)^2$$

$$d_{k,i-1} = x_k - \hat{x}_{i-1}$$

Note that in each iteration new weights are calculated for each solution based on the RMS of the differences to the combined solution of the previous iteration. However, x_k in the formula shown above can be interpreted as one dimensional or as a full position vector. Since the orbital solutions of the individual analysis centers are given in 3D space, there are two different variants. Either the differences of each spatial direction can be used together and one single RMS can be determined, or each spatial direction can be treated separately. In the latter case a separate RMS is determined per spatial direction (X,Y,Z), per solution and per iteration. The combination thus runs independently for each direction. Various tests have shown that the version with one weight per solution is generally better suited. If the procedure is aborted after the first iteration, this procedure corresponds to that used by the International GNSS Service (IGS) for the combination of GNSS satellite orbits from different ACs [5].

Simulations

Figure 2 shows that errors of reduced-dynamic orbit solutions are usually periodic. We thus simulated orbit solutions affected by once-per-rev periodic errors with different amplitudes and phases (see Fig. 3) according to:

$$f_i(t) = A_i \cdot \sin(\omega \cdot t + \phi_i)$$

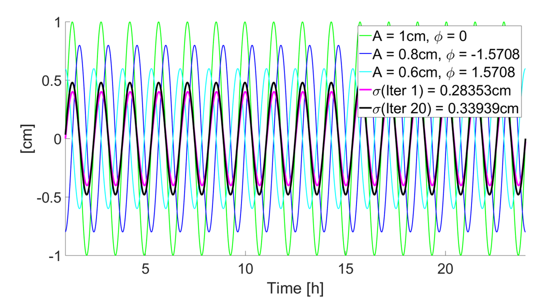

Figure 3: Simulations of phase shifts and their impact on the variance component estimation

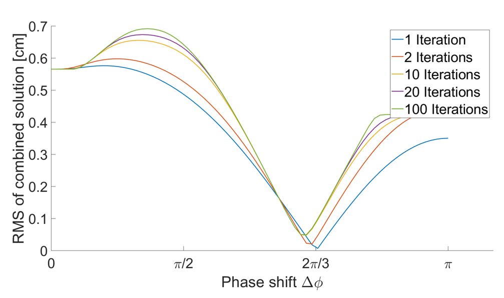

Figure 4: Resulting RMS with different phase shifts

Figure 4 shows the quality of the combination based on three individual simulated solutions. The resulting RMS with respect to the true solution is plotted as a function of the mutual phase shift ($\Delta\phi$) between the simulated periodic errors. We clearly see a minimum. The exact location of the minimum depends on the amplitudes of the simulated errors of the individual solutions.

In general, the simulation shows that the larger the phase shifts between the individual solutions, the smaller the RMS of the combined solution. The result for three individual solutions shown here can be generalized to any number of solutions, which could also be confirmed by simulations. The minimum occurs for $\Delta\phi_{i,j} = 2\pi/N, \forall i, j \in k$, where N = Number of solutions. In other independent simulations with more individual solutions (not shown here) it could be shown that the RMS of the combination becomes smaller as soon as the mean value of the phase shifts approaches the value $2\pi/N$. In these simulations, both the amplitudes of the individual periodic errors and their relative phase positions were randomly generated. In order to generate combined solutions from real data, which ultimatively shall be of better quality than the individual solutions, periodic orbit errors need to fulfill the above mentioned criterion. The determination of the phases of the individual solutions showed that all solutions have indeed different phases with non-zero mean. From this result and that of the simulation it can be concluded that the variance component estimation is able to reduce the errors observed in real orbit solutions although they are not random but systematic (periodic).

SLR validation of real solutions

In order to independently validate if the VCE, especially as an iterative method, is advantageous for the combination of different LEO orbit solutions, Satellite Laser Ranging (SLR) residuals are computed for the combined solutions as well as for the individual orbit solutions of each AC. The validation was performed for the time period from 1 January 2017 to 27 January 2018. For the validation of the SLR measurements, only measurements from a subset of well performing stations were used. The list of accepted stations was compiled on the basis of externally determined quality of the the measurements [2]. A threshold of 20 cm was set for the outlier detection of the residuals.

	AIUB	CPOD	TUM	CNES	DLR
MEAN	-0.607	-0.069	-0.264	-0.045	-0.443
STD	1.179	1.238	1.325	1.385	1.179
RMS	1.328	1.242	1.353	1.388	1.262

	TUD	ESOC	EUM	VCE_1	VCE_{10}
MEAN	-0.539	0.041	-0.279	-0.319	-0.364
STD	1.108	1.372	1.724	1.092	1.080
RMS	1.234	1.374	1.748	1.140	1.142

Table 2: SLR validation of individual solutions and the combined orbit by using variance component estimation (cm), the subscript for the VCE solutions denotes the number of iterations

It can be seen that the standard deviation (STD) of the combination is smaller than that of any of the individual solutions. It is also noteworthy that the mean value of the combined solution is not the smallest, but rather represents an average of the mean values of the individual solutions. This issue underlines the need for applying a Helmert transformation before the combination. It is also evident that the mean value and the RMS assume larger values as the number of iterations increases.

Conclusions

The method of variance component estimation can be successfully applied to the combination of precise orbit solutions of the Sentinel-3A satellite computed in the frame of the Sentinel POD Quality Working Group. It could be shown that the STD of the SLR measurements is further improved by the combination process. However, the mean value of residuals is worse than for some of the individual solutions. A possible approach to improve is a preceding Helmert transformation to eliminate systematic differences before performing the combination. Both the simulation of the periodicities and the values of the SLR validation for the mean value and RMS show that more than one iteration can also be disadvantageous in the presence of systematic errors, which requires further investigation. An improvement of the combination method is also conceivable, especially with regard to the correlated spatial directions and correlations in time.

References

(1) Jean, Y., U. Meyer, A. Jäggi (2018): Combination of GRACE monthly gravity field solutions from different processing strategies, Journal of Geodesy, 92(11), 1313-1328
(2) POD-Sentinel-3-SLR-Yearly-Report-2017,GMV, https://sentinel.esa.int/web/sentinel/missions/sentinel-3/ground-segment/pod/documentation
(3) Regular-Service-Review-October-2017-to-January-2018,GMV,[2]
(4) K.-R. Koch, 1999, Parameter Estimation and Hypothesis Testing in Linear Models, Springer
(5) Beutler, G., J. Kouba, T. Springer (1995): Combining the orbits of the IGS Analysis Centers. Bulletin géodésique, 69(4), 200–222

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